(54) Title: METHODS AND APPARATUS FOR CONCURRENTLY PROCESSING DATA FROM MULTIPLE TRACKS OF AN OPTICAL STORAGE MEDIUM
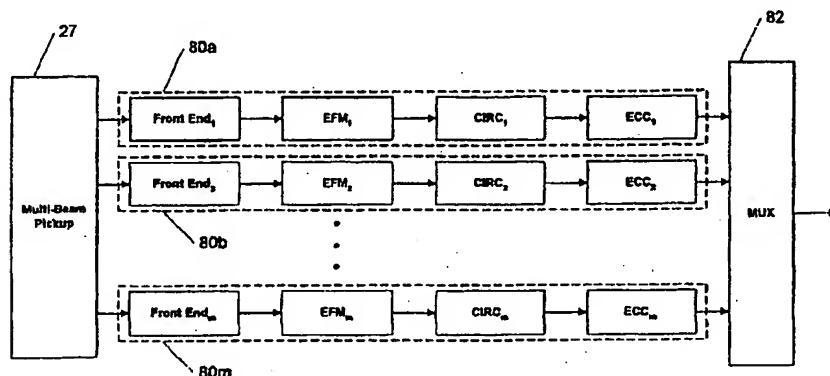
(57) Abstract

Methods and apparatus are provided for synchronously reading data from multiple tracks of an optical disk using multiple illumination beams. Circuitry is provided for use with a photodetector array to read and buffer data in parallel from the multiple adjacent tracks, while asynchronously providing processed data to a host processor. Circuitry is further provided for concurrently processing the signals read from the multiple data tracks to recover the data stored in the tracks.

METHODS AND APPARATUS FOR CONCURRENTLY
PROCESSING DATA FROM MULTIPLE TRACKS
OF AN OPTICAL STORAGE MEDIUM

Field of the Invention

5   This invention relates to methods and
apparatus for retrieving information from an optical
disk at high data rates by simultaneously and
synchronously reading multiple adjacent tracks.

Background of the Invention

10   Due to their high storage density, long data
retention life, and relatively low cost, optical disks
are becoming increasingly popular as a means to
distribute information. Large format disks have been
developed for storing full length motion pictures. The
15 compact disk (CD) format was developed and marketed for
the distribution of musical recordings and has replaced
vinyl records. High-capacity, read-only data storage
media, such as CD-ROM and DVD, have become prevalent in
the personal computer field, to the point that the DVD
20 format may soon replace videotape as the distribution
medium for video information.

An optical disk is made of a transparent disk
or substrate in which data, in the form of a serial
bit-stream, are encoded as a series of pits in a

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1.6 μm, while DVD employs a track pitch only about one-
half as wide.

Previously known methods of increasing the
data transfer rate of optical disk readers have focused
5 on increasing the rate at which the pits pass by the
pickup assembly by increasing the rotational speed of
the disk itself. Currently, drives with rotational
speeds of up to 16× standard speed are commercially
available, and even faster speeds have been achieved by
10 moving to constant angular velocity designs. However
higher disk rotational speeds place increasing demands
on the optical and mechanical subsystems within the
optical disk player, create greater vibration, and may
make such players more difficult and expensive to
15 design and manufacture.

Other previously known techniques for
increasing average data transfer rates involve methods
to intelligently anticipate future read requests by a
host processor. It has been observed that data access
20 by computers frequently exhibit "locality of
reference," which means that a future data access will
be local, in either space or time, to a previous data
access. Thus a CD-ROM drive or controller can "read
ahead" and buffer the data that the host processor is
25 likely to request next. When the host processor next
requests data from the optical disk drive, the drive
first checks if the requested data have already been
read and buffered. If the data have already been
buffered, the drive simply sends the buffered data to
30 the host, avoiding the delays associated with
repositioning the pickup assembly and reading data from
the optical disk itself. While such caching techniques
may speed up average data access times, the maximum
data transfer rate is still limited by the rotational

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processed requires use of high performance devices to
perform the functions at each of the stages in the
processing chain.

5   The present application is directed to an
improvement in the system described in the above-
incorporated patent, wherein the multiplexer is moved
to a later position in the processing chain, so that
the plurality of data streams from multiple tracks on
the disk may be demodulated, decoded, and error

10   corrected before being multiplexed into a single data
stream. Apparatus in accordance with the present
invention may use a plurality of inexpensive,
relatively low performance devices to perform the steps
of demodulation, decoding, and error correction, while

15   delivering throughput similar to that achieved by a
high performance device performing these operations on
a single multiplexed stream of data. Using the
techniques of the present invention, it may be possible
to construct a high performance system for processing

20   the multiple data streams read from an optical disk,
and which has a higher throughput than other similar
systems, using standard low cost components.

It would therefore be desirable to provide
apparatus and methods which permit simultaneous

25   processing of data from multiple tracks in an optical
disk reader.

It would also be desirable to provide
demodulation, decoding, and error correction circuitry
having higher throughput and at lower cost than

30   previously known circuitry for processing the data from
multiple tracks in an optical disk reader.

<u>Brief Description of the Drawings</u>

FIG. 1 is an illustrative block diagram of a previously known single beam optical disk reader;

FIG. 2 is an illustrative block diagram of a

5   multi-beam optical disk reader;

FIG. 3 is a block diagram of a multi-beam optical disk reader built in accordance with the principles of the present invention;

FIG. 4 is a block diagram of the front end

10   circuitry for extracting data from the signals output by the pickup assembly of FIG. 3;

FIGS. 5A, B, and C are block diagrams of the demodulator circuitry, decoder circuitry, and error correction circuitry, respectively, of the optical disk

15   reader of FIG. 3;

FIGS. 6 and 7 are block diagrams of alternative embodiments of multi-beam optical disk readers built in accordance with the principles of the present invention; and

20   FIG. 8 is a block diagram of an alternate arrangement for the processing chain of an optical disk reader built in accordance with the principles of the present invention.

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controller 24, the data signal is further processed by
eight-to-fourteen (EFM) demodulation circuitry 17,
Cross Interleaved Reed-Solomon Code (CIRC) decoding
circuitry 18, error correction code (ECC) circuitry 19,
5   and subcode circuitry 16. Controller 24 also controls
focus and tracking circuitry 14, as well as buffer 20
and interface 22.

For a digital audio system, the data signals
may be processed into suitable analog signals (using
10 circuitry not shown) connected to audio means 21.
Similarly, if the optical disk contains video images,
the data signals may be processed for display on a TV
or monitor. In computer applications the data signals
are typically transferred from buffer 20 to host
15 processor 23 via interface 22.

Spindle motor 11 spins optical disk 100 at a
speed that depends upon the radial location of pickup
assembly 12 (for example, for a 1× CD-ROM spindle
speed, approximately 200-500 RPM), to maintain a
20 constant linear velocity of an optical disk track
relative to pickup assembly 12. For a CD-ROM format,
this linear velocity is generally 1.4 m/s, while for
the DVD format it approaches 4 m/s. Pickup assembly 12
typically includes a laser diode that illuminates only
25 a single data track on optical disk 100 and an optical
sensor onto which an image reflected from the optical
disk is projected. The intensity, or other property,
of the light beam reflected from the surface of optical
disk 100 is modulated by inhomogeneities in the
30 reflective surface of the optical disk (i.e., bumps or
pits, referred to hereinafter as "data spots") arranged
in spiral or circular tracks on optical disk 100.

Pickup assembly 12 includes circuitry to
generate an electronic signal representative of the

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Demodulated data words are also provided to subcode
processor 16 which extracts data, such as block
numbers, or song titles, that may be recorded in the
subcode channels embedded in each block of data words.

5   For video and audio optical disk players, the
data from CIRC decoder 18 represents, in digital form,
the video or audio signal that was originally recorded
and stored on the disk. These signals may then be
converted to analog signals and the original recorded

10   signal reproduced using conventional audio or video
devices 21. Errors in the recovered audio or video
signals are handled by interpolation and filtering
circuitry (not shown) to calculate a value to use in
place of the erroneous data. Because of the

15   interpolation process, isolated errors in an audio or
video signal are unlikely to be noticed when listening
to the audio or viewing the video signals.

             However, since a single bit error in data
representing a computer program may render the program

20   inoperable or the data unusable, optical disks used for
the storage and distribution of data and programs must
have very low data error rates. To reduce the data
error rates to acceptably low levels, error correction
codes (ECC) are added to the data when it is recorded

25   to the disk. ECC circuitry 19 uses error correcting
codes to detect and possibly correct errors in the
data. Finally, the data are buffered in memory buffer
20 for transfer to host processor 23 via interface
circuitry 22. Controller 24 coordinates operation of

30   each of the optical disk reader subsystems and to
control the operation of the optical disk reader as a
whole.

             Referring now to FIG. 2, an optical disk
reader similar to that described in U.S. Patent Number

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FIG. 1, except that multiple bit streams are processed
concurrently, so additional circuitry is provided for
buffering and synchronizing data transfers to
subsequent processing circuitry. Front end circuitry
5   30 also includes a multiplexer for routing multiple
data streams to demodulation circuitry 32 in the form
of a single multiplexed data stream.

Demodulation circuitry 32, subcode circuitry
31, decoder circuitry 34, and error correction
10 circuitry 36 of optical disk reader 25 are all similar
in operation to their counterparts in optical disk
reader 10 of FIG. 1. They differ principally in that
they may be required to handle a much greater data
throughput than similar circuitry used in single-beam
15 optical disk reader 10.

Buffer memory 33 is provided to buffer the
data read from the multiple data tracks, and to
decouple the process of reading data from optical disk
100 from the process of transferring the data to host
20 processor 37. Buffer 33 therefor is large enough to
hold about as many data blocks from multiple data
tracks of optical disk 100 as can be read in one
revolution of optical disk 100. Controller 38 maps
data from the multiple data tracks to memory 33 so that
25 individual data blocks will be correctly assembled
without overwriting one another. As will be
appreciated by those of skill in the art of buffer
design, this mapping may be either dynamic or static.

Description of the Present Invention
30   Referring to FIG. 3, multi-beam optical disk
reader 40, constructed in accordance with the
principles of the present invention is described.
Multi-beam optical disk reader 40 is very similar to

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titles, that may be recorded in the subcode channels embedded in each frame of data words.

Decoder circuitry 46 uses a form of Cross Interleaved Reed-Solomon Code, such as CIRC for CD-

5 formats and PI PO structure for DVD, to decode the frames of data received in each of the data streams. The decoded frames are then assembled into sectors, which contain the data from multiple frames, and are made available to error correction circuitry 48 as

10 multiple streams of sectors. Each sector contains a sector type identifier, used for determining which type of error correction or other processing to perform on the sector. Sectors also contain synchronization codes, data, and may contain error correction codes.

15   If the sector type identifier indicates that a sector contains error correction codes, error correction circuitry (ECC) 48 uses the error correction codes to detect and possibly correct errors in the data. The corrected data from each of the data streams

20 is then made available to buffer memory 50 through multiplexer (MUX) 52. Buffer memory 50 uses MUX 52 to select one of the data streams, and transfers one sector of corrected data from ECC circuitry 48 to memory. Buffer memory 50 permits stored data to be

25 transferred to host processor 23 via interface circuitry 22.

Controller 54 coordinates operation of each of the optical disk reader subsystems and controls the operation of the optical disk reader as a whole.

30   FIG. 4 shows a detailed view of front end circuitry 42, constructed using a separate PLL for each track. Multi-beam pickup assembly 27 outputs track data signals, $T_1 \ldots T_m$, corresponding to m tracks being

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data words from one track into demodulated data words,
or symbols, and assembles the symbols into frames.
Additionally, demodulator units 60 may extract subcode
data from the data stream, and send the subcode data to
5   subcode processor 43.

For an 8× multi-beam CD-ROM reader, each
demodulator unit 60 assembles 58,800 frames per second,
each frame containing 32 bytes, for a total of
approximately 1.9 million bytes per second. If the
10 data from a seven beam, 8× system were combined into a
single stream at the demodulator stage, the combined
data stream would have a data rate of approximately
13.2 million bytes per second. Thus, applicant expects
that retaining multiple data streams will permit use of
15 a greater number of lower cost (slower) components.

FIG. 5B shows decoder circuitry 46, which
comprises one single-track Cross Interleaved Reed-
Solomon Code (CIRC) decoder unit 62 for each of the m
data tracks being processed. Data from demodulator
20 units 60 are sent into CIRC decoder units 62. Each of
CIRC decoder units 62 decodes data from a single track,
and assembles the data into sectors, which are sent to
error correction circuitry 48.

For an 8× multi-beam CD-ROM reader, each CIRC
25 decoder unit 62 assembles 600 sectors per second, each
sector containing 2352 bytes, for a total of
approximately 1.4 million bytes per second. If the
data from a seven beam, 8× system were combined into a
single stream at the decoder stage, the combined data
30 stream would have a data rate of approximately 9.9
million bytes per second.

FIG. 5C shows error correction circuitry 48,
which comprises one single-track error correction unit

data rate is highest, while using circuitry which
processes a single data stream for later stages, such
as decoding and error correction. Accordingly, in
optical disk reader 60, Multiplexer 62 has been placed
5   between demodulation circuitry 44 and decoder circuitry
34 in the processing chain. Multiplexer 62 combines
the data from all of the single-track demodulation
units of demodulation stage 44 into a single data
stream. As shown in FIG. 6, multiplexer 62 sends the
10   combined stream of data to buffer memory 50, where it
is stored until the frames are requested by host 23, or
are no longer needed. Alternatively, if later stages
are capable of handling the throughput required to
process the combined data stream, buffer memory 50 can
15   be placed at the end of the processing chain, and the
combined data stream from multiplexer 62 may be sent
directly into decoder stage 34.

        FIG. 7 shows another alternative embodiment,
in which multiplexer 66 is located between decoder
20   circuitry 46 and error correction circuitry 36 in the
processing chain. Multiplexer 66 combines the data
streams from the single-track decoder units in decoder
stage 46 into a single data stream, which is stored in
buffer memory 50. If the error correction stage is
25   capable of handling the throughput required to process
the combined data stream, buffer memory 50 may be
placed at the end of the processing chain, after error
correction stage 36.

        FIG. 8 shows a yet further alternative
30   arrangement of the processing chain for a multi-beam
optical disk reader constructed in accordance with the
principles of the present invention. The processing
chain shown in FIG. 8 is arranged according to which
beam is being processed, rather than according to

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and modifications may be made without departing from
the invention. It is intended in the appended claims
to cover all such changes and modifications which fall
within the true spirit and scope of the invention.

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5.   The apparatus as defined in claim 4,
wherein the demodulation stage, decoding stage, and
error correction stage are all part of the concurrent
portion of the processing circuitry, the buffer is part
of the serial portion of the processing circuitry, and
the multiplexer is disposed between the error
processing stage and the buffer.

6.   The apparatus as defined in claim 4,
wherein the demodulation stage is part of the
concurrent portion of the processing circuitry, and the
decoding stage, error correction stage, and buffer are
part of the serial portion of the processing circuitry.

7.   The apparatus as defined in claim 6,
wherein the multiplexer is interposed between the
demodulation stage, and the buffer.

8.   The apparatus as defined in claim 6,
wherein the multiplexer is interposed between the
demodulation stage and the decoding stage.

9.   The apparatus as defined in claim 4,
wherein the demodulation stage and decoding stage are
part of the concurrent portion of the processing
circuitry, and the error correction stage and buffer
are part of the serial portion of the processing
circuitry.

10.   The apparatus as defined in claim 9,
wherein the multiplexer is interposed between the
decoding stage and the buffer.

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sampling the plurality of data signals to
produce a plurality of digital data streams;

concurrently processing the plurality of
digital data streams;

multiplexing the plurality of digital data
streams into a single serial data stream; and

processing the serial data stream to produce
the formatted data.

18.   The method of claim 17, wherein the step
of concurrently processing the plurality of digital
data streams further comprises the steps of:

concurrently demodulating the plurality of
digital data streams;

concurrently decoding the plurality of
digital data streams; and

concurrently error correcting the plurality
of digital data streams.

19.   The method of claim 18, wherein the step
of multiplexing the plurality of digital data streams
follows the step of concurrently error correcting the
plurality of digital data streams.

20.   The method of claim 17, wherein the step
of concurrently processing the plurality of digital
data streams further comprises the step of concurrently
demodulating the plurality of digital data streams, and
the step of processing the serial data stream further
comprises the steps of:

decoding the serial data stream; and

error correcting the serial data stream.

26. Apparatus for concurrently processing a plurality of streams of data simultaneously read from a plurality of tracks of an optical disk, the apparatus comprising:

a plurality of data stream processing circuits, each data stream processing circuit processing one of the plurality of data streams; and

a multiplexer for combining the outputs of the plurality of data stream processing circuits into a single data stream.

27. Apparatus as defined in claim 26, wherein each one of the plurality of data stream processing circuits comprises circuitry for demodulating a data stream.

28. Apparatus as defined in claim 27, wherein each one of the plurality of data stream processing circuits comprises circuitry for decoding a data stream.

29. Apparatus as defined in claim 28, wherein each one of the plurality of data stream processing circuits comprises circuitry for error correcting a data stream.
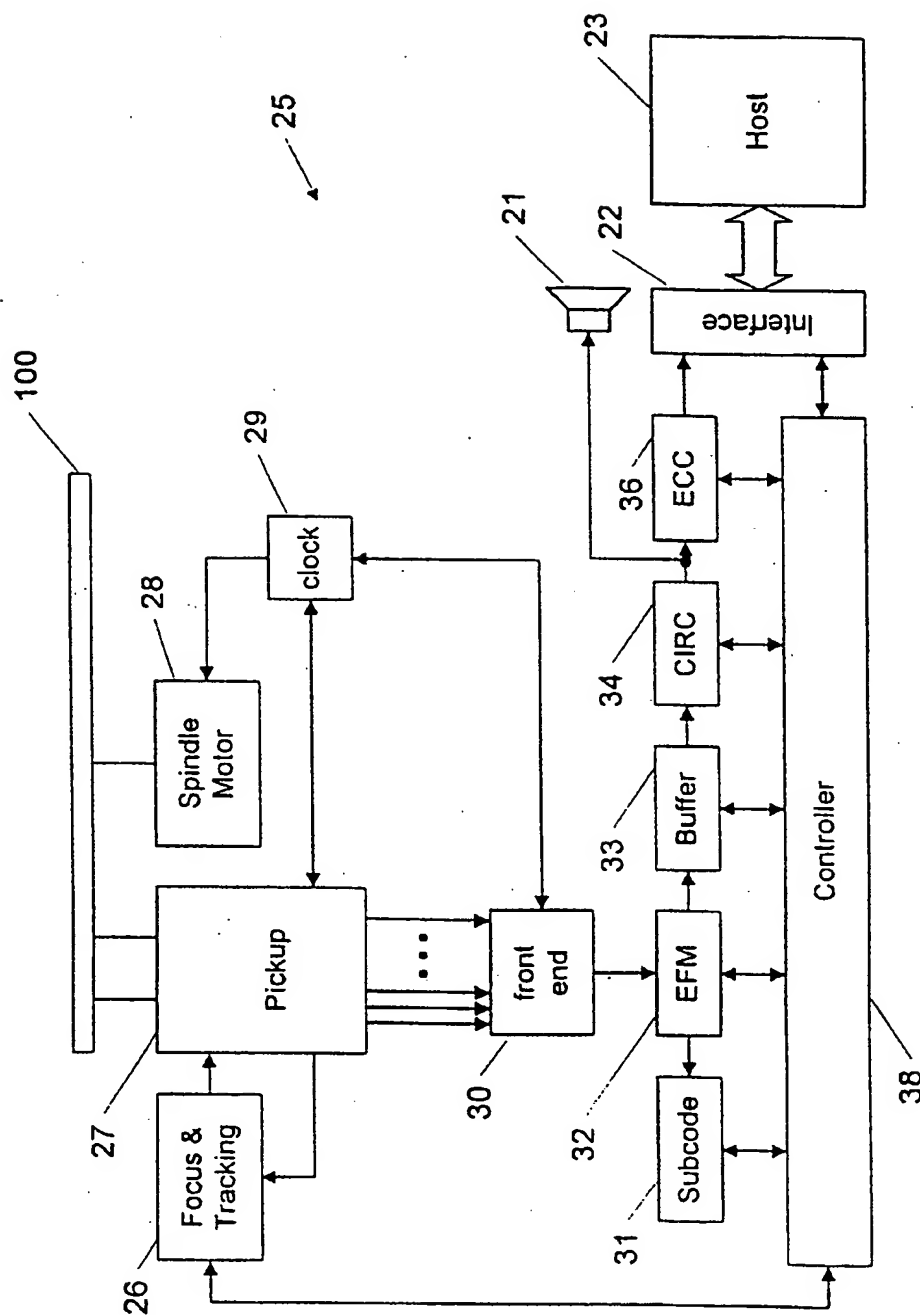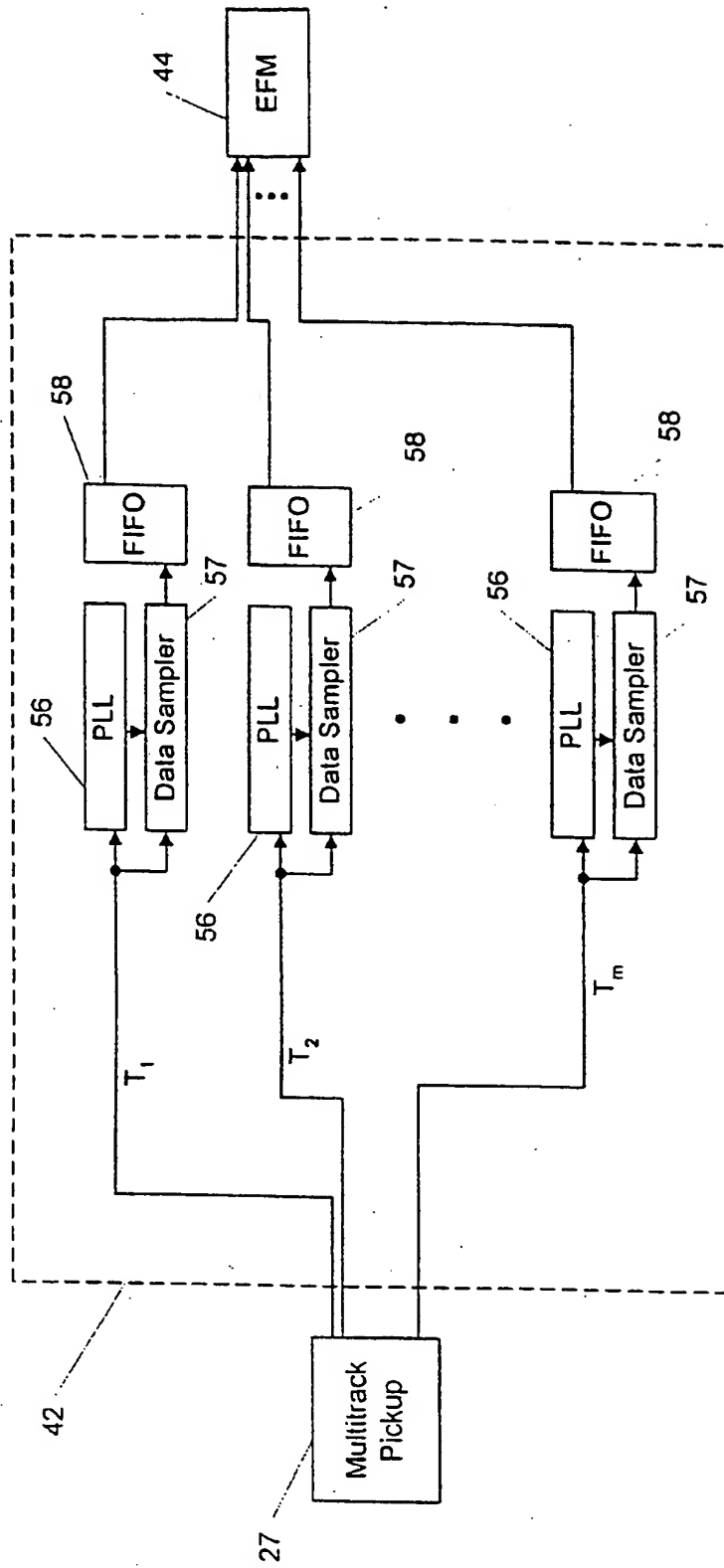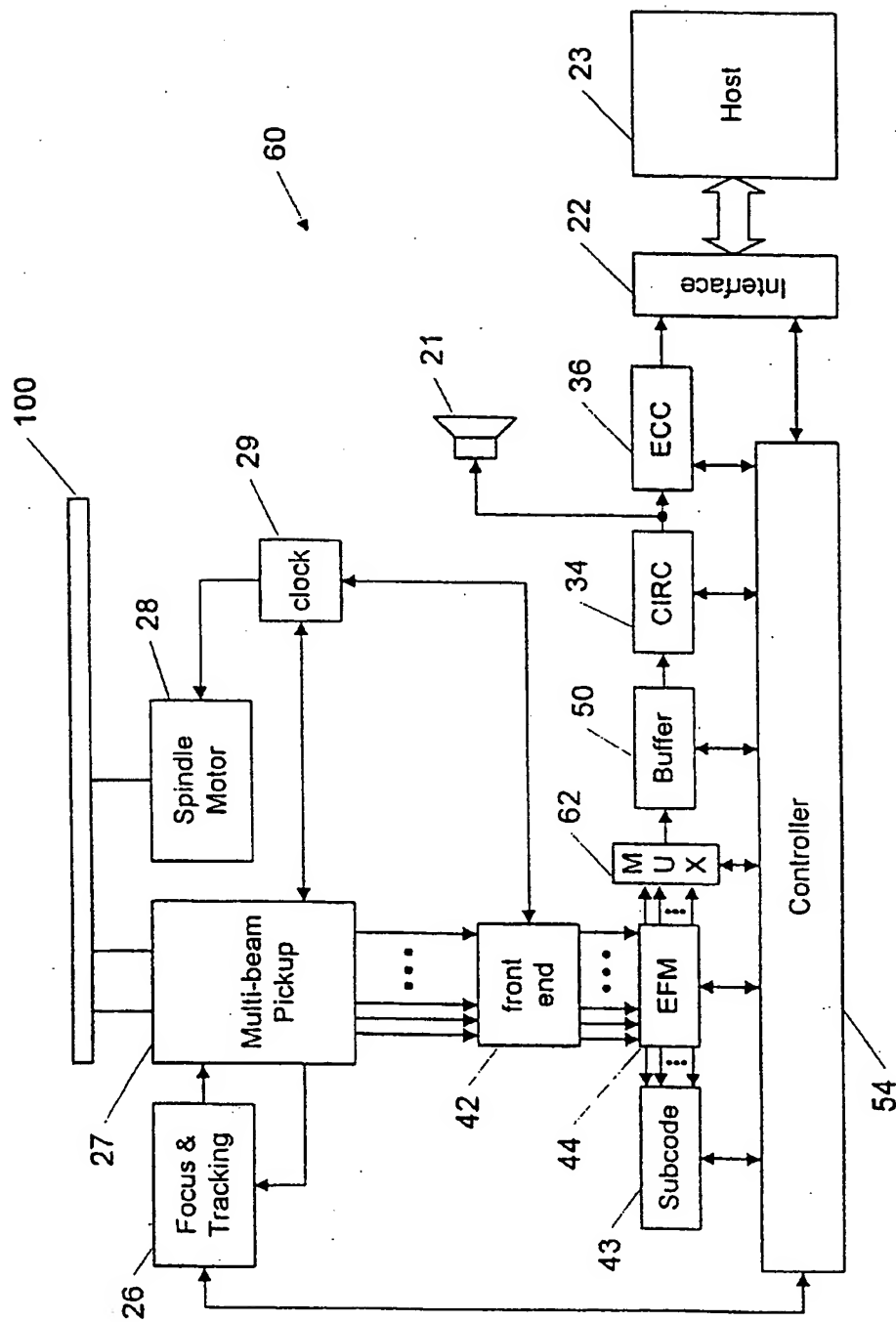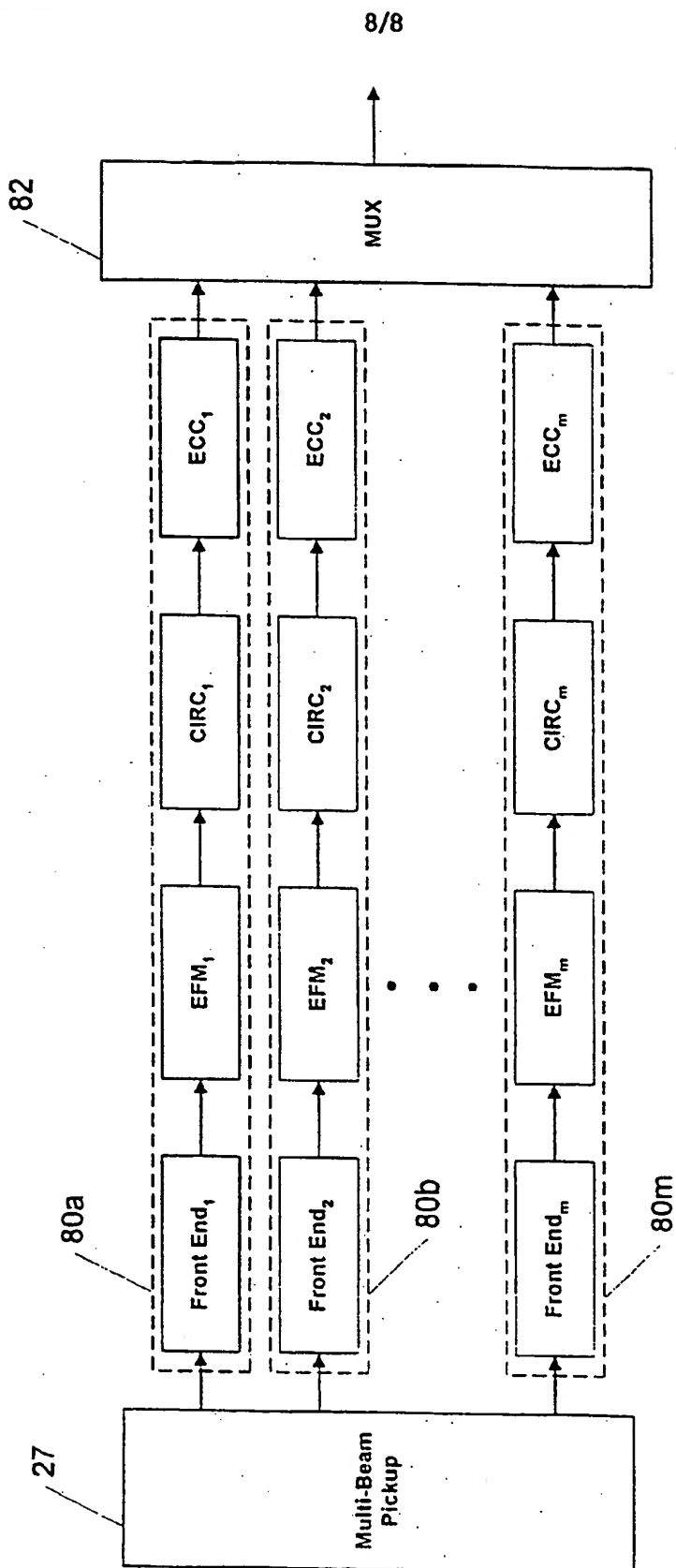
FIG. 2

FIG. 4

FIG. 6

FIG. 8

INTERNATIONAL SEARCH REPORT

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 0 714 096 A (SONY CORP) 29 May 1996 see abstract see column 3, line 18 - column 4, line 42; figures 1,2 ---	16
X	EP 0 712 119 A (MATSUSHITA ELECTRIC IND CO LTD) 15 May 1996 see page 6, line 42 - page 7, line 5 see page 12, line 34 - line 55; figures 2,14	1,2,17, 26,27
A	---	3,15,18
X	EP 0 273 384 A (MATSUSHITA ELECTRIC IND CO LTD) 6 July 1988 see figure 7 -----	1,2,12, 13,17, 24,26

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